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Keywords: hybrid flax; supersap bio-epoxy; mechanical properties; environmental resistance

composites [32]. However, in the present investigation, the treatments had little effect on (increasing) T_g through better interfacial adhesion. This primarily is attributed to the decrease in fiber strength, leading to fewer constraints on segmental flexibility. For the same reason, the highest and lowest loss modulus was found in untreated and BTCA treated composites with the maximum and minimum viscous dissipation, respectively.

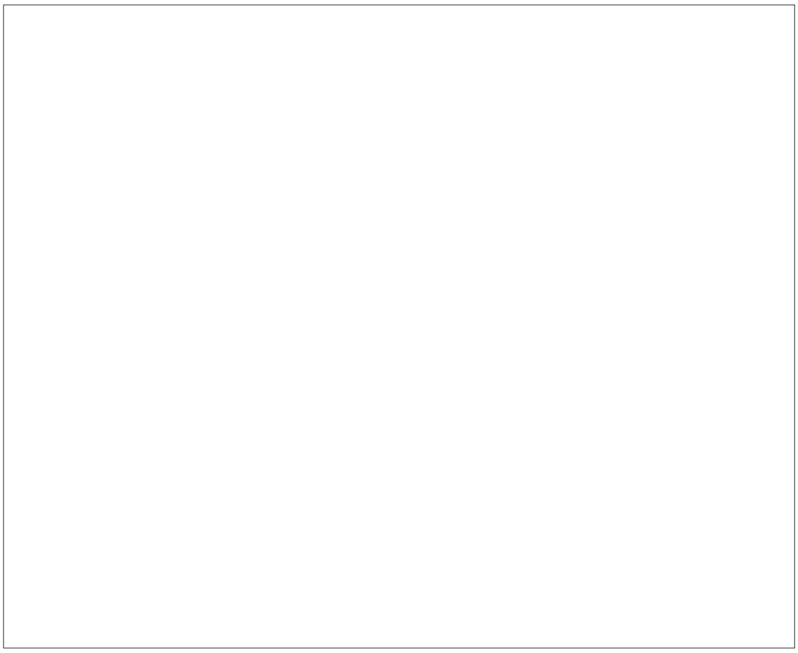

Figure 3. Effect of treatments on loss modulus of resin and FE composites.

Table 4. Thermal-mechanical properties of untreated and treated composites.

Testing material	T_g (Loss) (°C)	T_g 7 D Q /	Max E Š (MPa)	Max Tan /	B
Pure bio-epoxy	72.74	84.83	241	0.834	0
Untreated	77.32	82.43	430	0.144	1.69
NaOH treated	75.28	81.29	400	0.176	1.61
BTCA treated	75.49	82.00	337	0.188	1.58
APS treated	76.79	81.87	356	0.155	1.66
LD treated	75.55	82.30	420	0.161	1.64

The ratio of storage (elastic) and loss (viscous) modulus is called tan / (Figure 4). In comparison to the untreated composites, an increase in magnitude of tan / peak was observed in treated flax/supersap composites. Thus, it will tend to dissipate less energy with lower magnitude of damping peak in F R P S D U L V R Q W R W U H D W H G F R P S R V L W H V 7 K H [31] to reflect X G H impact properties of materials. As in the previous study, the untreated composites showed a rebound case subjected to the falling weight impact, while the treated composites broke longitudinally. The untreated FE composites had better damping property, thus dissipating more energy by internal friction.

Figure 4. Representation of flax/ R I U H V L Q D Q G) (F R P S R V L W H V with treatments.

The bonding properties between flax fibres could also be indicated quantitatively. According to the following equation, the bonding properties for various treated flax composites could be assessed by [24]:

$$L\,\frac{s\,F\,\dfrac{-\,f\,U_{o}}{-\,f\,U_{a}}}{d} \qquad (1)$$

where B is a parameter used to indicate the interfacial bonding strength; $-fA_a$ for composites; and $-fA_k$ for pure matrix; $_d$ is the fibre volume fraction which could be calculated from composite volume : $_a$), composite weight (M_b), fiber weight ratio (W D Q G U H V L Q $_m$) G H Q V L W \ !

$$_d\,L\,\frac{_a\,F\,\dfrac{_a\,H:s\,F\;_d;}{Q_k}}{a} \qquad (2)$$

The lower value of B parameter indicates lower interfacial strength. From the results summarized in Table 4, B value decreased after all the treatments, possibly owing to the loss of matrix or of fibre (strength).

3.2. Effect of Treatment on Quasi-Static Tension Properites

The tensile properties of flax/supersap composites were compared through different treatments (non-treated, NaOH, BTCA, APS and Laccase-Doga 7 H Q V L O H V W U H Q J W K D Q G < R X in Figure 5 The untreated flax/supersap composites exhibited tensile strength and tensile modulus of up to 185 MPa and 14 GPa, respectively. The NaOH treated composites displayed the tensile strength of about 178 MPa, less than 10 MPa reductions in tensile strength. The average tensile strength was observed to be at 175 MPa and 165 MPa for APS and Doga treated composites, respectively. Over 70% reduction of tensile strength was found for the BTCA treated flax/supersap laminates (51 MPa) compared to untreated composites (185 MPa). Clearly, these chemical treatments have no significant effect on improvement in ultimate tensile strength of the composites although they may have positive

Figure 7. Flax/supersap bio-epoxy composites samples with and without treatments after aging condition: (**a**) UV radiation for 552 h; (**b**) Xenon light for 500 h.

Table 5. Tension properties of hybrid flax/supersap bio-epoxy composites with different treatments in weathering conditions

Samples	Tensile Strength (MPa)			Tensile Modulus (GPa)		
	Normal	UV	Xenon	Normal	UV	Xenon
Untreated	185.4 ± 8.5	185.4 ± 7.8	172.2 ± 8.1	13.9 ± 0.4	14.0 ± 0.3	8.8 ± 0.4
NaOH	178.5 ± 6.4	146.9 ± 6.4	169.8 ± 6.5	11.9 ± 0.5	10.5 ± 0.4	11.8 ± 0.5
BTCA	51.7 ± 6.1	40.2 ± 5.8	45.9 ± 6.2	6.4 ± 0.6	5.4 ± 0.2	6.0 ± 0.2
APS	175.4 ± 6.2	157.3 ± 8.2	175.1 ± 6.2	11.3 ± 0.4	9.8 ± 0.5	11.5 ± 0.6
LD	164.5 ± 5.7	157.1 ± 7.0	160.3 ± 5.6	13.7 ± 0.4	13.7 ± 0.2	11.9 ± 0.3

4. Conclusions

The untreated new flax/epoxy composites (tensile strength of around 185 MPa) show a good potential to be used in automobile applications. Pure NaOH treatment is the most promising one among the treatments performed in this study. NaOH composites maintained the tensile strength of around 180 MPa; however, BTCA and other treatments decreased the tensile strength. The improvement in fibre/matrix wettability may not be able to compensate the reduction in fibre strength (due to the removal of interfibrillar matrix by general treatments). The fibre treatments had little effect on glass transition temperature (approximately 75 °C).

This work also suggests that the applied treatments for fibre/supersap bio-epoxy composites (57 wt% fibre ratio) can significantly improve Xenon aging resistance, but have little effect on UV aging. For UV and Xenon aging, the composites with modified flax mats did not show any visual change, which was a bit better than composites without flax modification. With respect to the tensile properties, the untreated composites had the best performance after UV exposure, while for Xenon exposure; the four treated composites (NaOH, BTCA, APS and LD) showed much better resistance.

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Author Contributions

The Jinchun Zhu designed the study, performed the experiments and analysis, and wrote the first draft of the manuscript. Other authors managed the analyses of the study.

Conflicts of Interest

The authors declare no conflict of interests. The funding sponsors had roles in the design of the study and in the decision to publish results.

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